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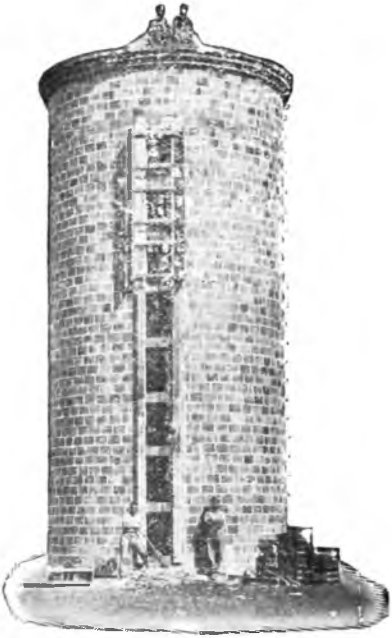
SILO CONSTRUCTION



AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE AND
THE MECHANIC ARTS

Agricultural Engineering Section

Ames, Iowa

INTRODUCTION.

The value of the silo as a means of utilizing almost the entire corn plant and producing valuable feed has been thoroly demonstrated. Silage is an economical and desirable feed and it is highly desirable that the use of the silo be more generally adopted.

The construction of silos has been for many years one of the principal lines of investigation followed by the Agricultural Engineering Section of the Iowa Agricultural Experiment Station. Results have been published in the following bulletins: No. 100, July, 1908, revised and republished July, 1909; No. 117, June, 1910, by J. B. Davidson and M. L. King, and No. 141, June, 1913, by J. B. Davidson. This new bulletin No. 189 is a revision of Bulletin No. 141.

The Agricultural Engineering Section does not recommend any one type of silo above all others. It has been demonstrated by experience that a number of different types of silos will each give satisfactory service if properly constructed.

It is well worth while for the silo builder to study the types and details of construction which will insure a reasonably permanent structure.

CONTENTS

SILO CONSTRUCTION

By C. K. Shedd and W. A. Foster.*

PART I—SILO REQUIREMENTS.

Every silo, to be successful, must incorporate certain essential features and in addition to these there are other desirable features which add to its value. The absolute essentials are those which are necessary to insure the preservation of the silage. Both the essential and the desirable features are here outlined independently of a consideration of the materials or the methods of their use in the silo.

ESSENTIAL FEATURES.

Imperviousness of walls. The fundamental principle in the preservation of silage is the retention of moisture within the silage and the exclusion of air. For this reason, the silo wall must be nonporous. Moisture must be prevented from passing out and air from passing in.

Strength of walls. The walls of a silo must be strong enough to resist the bursting pressure of the silage, which acts outward in all directions as the silage settles.

Smoothness of walls. To permit the silage to settle freely and to prevent the formation of air pockets the walls should be smooth on the inside and not have shoulders or offsets. Air pockets result in more or less spoiled silage.

DESIRABLE FEATURES.

Durability. To make a durable silo, material must be used which will resist the action of the weather, the constant wetting and drying, freezing and thawing in the winter season, and any disintegrating action due to the silage.

Wind Storm Resistance. The silo is tall and narrow, making it especially subject to damage by high winds during the time when it stands empty; therefore, special attention should be given to the design and construction of the silo that it will resist high winds.

Fire Proof Construction. It adds materially to the value of any building to be made of fire proof materials. The shape and general requirements of the silo make it especially well adapted to the use of masonry construction which is fire proof.

Convenience. A silo should be convenient for filling and so arranged that the silage may be easily removed from day to day during the feeding season. The doors should be so

*This bulletin is a revision of previous bulletin No. 141 by J. B. Davidson.

constructed that they can be put in place and removed with the least effort. They should permit easy access to the silo and allow the removal of the silage with the least possible amount of labor.

Good Appearance. This feature adds to the attractiveness and the value of the farm. A permanent silo of neat appearance is the most desirable silo to construct, other things being equal.

Frost Resistance. In Iowa the winters are so severe that it is difficult to construct a frost-proof silo. It is desirable to prevent freezing of the silage as far as possible. The amount of freezing depends to some extent on the construction of the silo, but it probably depends more on the location of the silo, that is, its exposure to cold winds and its being shaded from the sun. By keeping the surface of the silage a little lower at the wall than in the middle of the silo as it is removed in cold weather, freezing can be greatly reduced.

Simplicity of Construction. It is an advantage to purchase either a silo to be erected complete by the seller or else to select one ready for erection without the aid of skilled labor.

Low Cost. The silo which will furnish storage for silage at the least cost per ton is the silo to build, other points being equal.

Low Cost of Up-keep. A silo which must be adjusted for

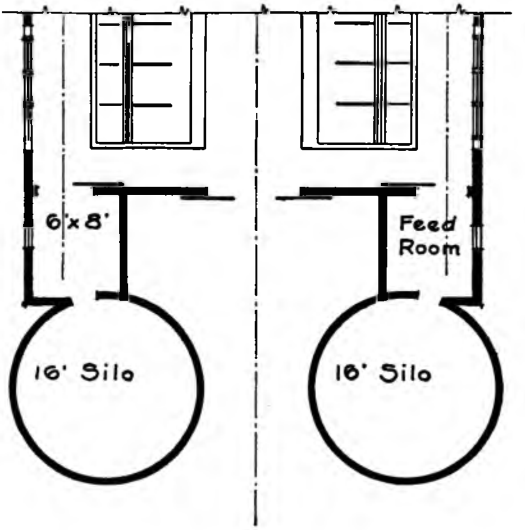


Fig. 1. Plan of silos and barn, showing a convenient arrangement for feeding.

shrinkage and expansion is of less value than one which does not need such attention. Sometimes this work may be neglected and the silo wrecked by wind. Some silos require painting to protect the material from the weather and to preserve good appearance. All parts of the silo should be equally durable and lasting.

LOCATION OF THE SILO.

For convenience in feeding, the silo is usually located so that the chute adjoins the feed alley of the barn.

Where it will not interfere with the convenience or the proper lighting of the barn, it is better to have the silo at the south rather than at north end of the barn. The protection of the silo from north winds and the exposure to the sun will reduce trouble from frozen silage.

Fig. 2. New dairy barn on college dairy farm.

The silo should be so located that it will be convenient to set the silage cutter and engine and to drive in with loaded wagons when the silo is to be filled.

PART II—THE DESIGN OF SILOS.

Under this heading will be discussed some features of silo construction common to all types of silos.

DIAMETER, HEIGHT, AND CAPACITY.

A silo of larger diameter will cost less per ton capacity than a smaller diameter silo, both being the same height. Again, the silo of greater height of the same diameter will hold more silage per foot height than the lower silo. The silage in the lower part is denser due to the great pressure from the high column of silage above.

The effect of height on capacity may be seen by reference to Table I, which indicates for instance that a silo 50 feet high has about twice the capacity of one 30 feet high of the same diameter. It is also true that a larger percentage of mouldy and inferior silage is found near the top than lower down in the silo. A certain weight is necessary to compress the silage and exclude the air so as to insure perfect preservation.

The diameter of the silo is limited by the necessary rate of removing the silage to prevent spoiling. In moderate

TABLE I. CAPACITY OF ROUND SILOS.

Data on silo capacity given in this table is based on the weighing of silage for five years in from three to five silos at the University of Nebraska Farm, and reported by Prof. L. W. Chase in Circular No. 1 of the University of Nebraska Agricultural Experiment Station.

Inside Diameter	Height	Capacity Tons	Amount that should be fed daily, lbs.
10	25	31.8	525
10	30	40.6	525
10	35	50.7	525
12	30	58	755
12	35	73	755
12	40	88	755
12	45	104	755
12	50	120	755
14	30	80	1030
14	35	99	1030
14	40	120	1030
14	45	141	1030
14	50	164	1030
16	30	104	1340
16	35	129	1340
16	40	156	1340
16	45	184	1340
16	50	214	1340
18	30	132	1700
18	35	164	1700
18	40	198	1700
18	45	234	1700
18	50	271	1700

TABLE II—AMOUNT OF SILAGE FED PER DAY.

This table furnished by the Animal Husbandry Section.

Kinds of Stock.	Daily Ration Pounds.
Beef Cattle	
Wintering calves, 8 months old	15-25
Wintering breeding cows	30-50
Fattening beef cattle 18-36 months old	
First stage of fattening	60-30
Latter stage of fattening	30-12
Dairy Cattle	
Dairy Cows	25-45
Dairy Heifers 1 to 2 years	10-20
Bulls	10-20
Sheep	
Wintering breeding sheep	2-6
Fattening lambs	1-3
Fattening sheep	1-4

If other roughage is fed as in case of sheep or cattle, they will eat less silage. Two and one-half to three pounds silage replaces one pound hay and some grain in addition.

weather, when silage is exposed to the air for more than a day it begins to spoil. In well settled silage, if one and one-half to two inches are fed from the surface daily the silage will remain fresh provided the weather is cool. In the summer the silage should be fed out at the rate of two to three inches per day. Table I shows the number of pounds of silage that should be fed daily from different sizes of silo in order to feed out about two to two and one-half inches per day. The rate of feeding may be a little slower than this in winter and a little faster in the summer.

Table II may be used in connection with Table I to find the diameter of silo that can be used. Take the smallest amount of stock to be fed from the silo at any time and find the pounds required per day from Table II; then find from Table I the largest diameter of silo that will keep the silage fresh at this rate of feeding. A height then may be selected to give the required capacity for the feeding season, or it may be necessary to build two silos to get sufficient capacity.

The mistake has often been made of building the silo too large in diameter so that when it is desired to feed only a small amount of stock the silage cannot be kept fresh. Silos 16 feet in diameter are found to be satisfactory for medium to large stock farms. A great many farms carrying smaller amounts of live stock should have 14 foot or 12 foot silos. A dairy farm should have a silo of small diameter for summer feeding. The height of the silo should be at least twice the diameter. A height of 30 to 35 feet is desirable for a wooden silo. For a masonry silo a height of forty to fifty feet is safe and satisfactory.

THE FOUNDATION.

Any permanent building, especially if of masonry construction, should rest upon a foundation broad enough to prevent appreciable settling and deep enough to rest upon soil which is never disturbed by frost. Wooden silos are often built with foundations extending only about two feet below the ground surface. If no pit is used this foundation is satisfactory, provided the soil is porous and well drained so that there will not be enough heaving action due to frost to crack the foundation wall. For a wooden silo the foundation should extend at least a foot above the ground so that the wood will be kept dry. For a masonry silo the foundation need not extend more than six inches above the ground.

Concrete is the material most generally used for silo foundations in Iowa. The most common method of construction

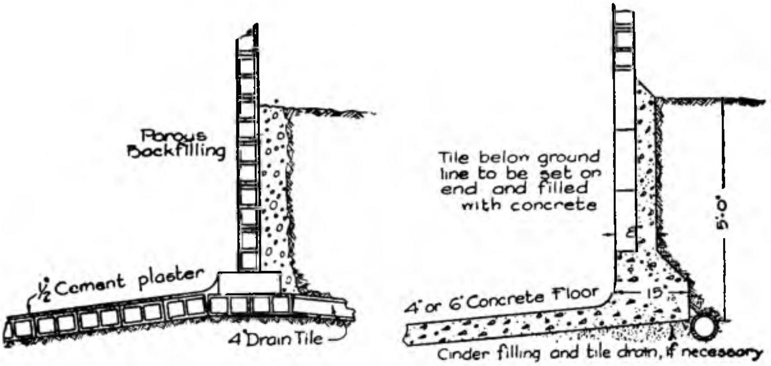


Fig. 4. Foundation at left constructed entirely of clay blocks. Foundation at right constructed of blocks and concrete.

is to mark out and dig a circular trench about ten inches wide and the proper diameter to fit the silo. This trench should be three and one-half to four feet deep. If the soil is porous or very dry the trench should be lined with tar paper to prevent water from being drawn out of the concrete before it has had time to set. Wooden forms must be constructed for the portion of the foundation extending above the ground. Care should be used to get the top of the forms set level all around.

Concrete should be mixed and placed carefully as explained in the discussion of the monolithic concrete silo in Part III of this bulletin. Large pieces of rock, say six inches in diameter, may be embedded in the concrete below the ground to reduce the cost. Above the ground the wall should be reinforced with steel as shown in Plate I. It is safer to use reinforcing below ground also. Many silo foundations are built without reinforcing, but a great many of them crack, especially if the foundation wall extends above the silo floor.

For the Iowa silo or for monolithic concrete or concrete block silos the foundation wall may be the same construction as the wall above ground. This wall is placed on a concrete footing about one foot in width and four inches deep and four feet below the ground. This construction proves satisfactory where the ground is well drained. If the silo pit is to be excavated anyway, this is a much cheaper construction than the heavy foundation wall described above. In poorly drained soil the heaving action of frost is likely to injure a four inch wall such as used above ground.

DRAINAGE.

Drainage is of great importance and should receive more consideration than is usually given to it in the construction of farm buildings, especially of masonry silos. Any soil will support a greater load when dry than when wet. This is especially true of clay. The heaving action of frost is due entirely to the moisture contained in the soil, which expands with an almost irresistible force upon freezing. For these considerations, unless the foundation lies in dry, well drained soil, a drain tile should be used to remove the ground water. To assist the water in getting into the drain, the foundation and floor may be placed upon a bed of gravel or cinders. Fig.

Fig. 5. Excavation for silo showing tile in place for draining foundation.

5 shows where the tile may be located, and also a bed of gravel for facilitating the drainage. If gravel or cinders are used, they should be well tramped before the foundation is put in place.

Fig. 4 shows two types of foundation and the location of tile drains.

THE SILO PIT.

Dirt is sometimes excavated from inside the foundation wall of a silo, thereby adding perhaps three and one-half feet to the depth of the silo. This proves satisfactory provided (1) that there is no seepage at any time from the surrounding soil into the silo pit and (2) that the silo wall is so placed on the foundation that there is no offset on the inside at the top of the foundation.

There are a good many locations free from seepage. In some parts of Iowa, however, experience with silo pits has been unsatisfactory due to the fact that seepage unfavorably affects the quality of silage.

With a wood stave silo it is not advisable to try to set the inside of the staves flush with the inside of the foundation wall. Some allowance must be made for shrinkage which will take place after the silo is erected. With the wood hoop silo or any masonry silo the inside of the wall may be set flush with the inside of the foundation, and this should always be done if the silo pit is to be used. Some builders have an idea that the silo wall must rest on the middle of the foundation wall. This is entirely unnecessary with the silo since the wall is circular in shape and therefore cannot tip in due to weight placed off center.

Silo pits are sometimes used when there is an offset at the top of the foundation. In this case the silage must be very carefully and thoroly tramped in the pit; otherwise an air pocket will be formed at the foundation wall as the silage settles and this will result in considerable spoiled silage.

In case the pit is used it may be advisable to cement plaster the inside of the foundation wall in order to make a smooth surface. This should be done while the concrete is still green and the surface should be thoroly cleaned and wet.

THE FLOOR.

Where the silo rests upon dry clay and where the foundation is deep enough to prevent undermining by rats, the earth floor is fairly satisfactory. A thin layer of straw may be placed over the floor before filling to prevent the mixing of silage and earth when the silage is fed out.

A concrete floor is desirable as it is rat proof and may be thoroly cleaned without any mixing of earth with silage. A silo floor need not be thick or expensive, since the weight of the silage, though very great, is distributed evenly over the surface and would be just as firmly supported if the floor were not used. A concrete floor two to four inches thick is sufficient.

THE WALLS.

Silo walls must be designed to resist the bursting pressure due to the silage. In the stave silo the hoops accomplish this purpose. In masonry silos steel reinforcing rods are used for the same purpose, this steel being embedded in the mortar joint or in the concrete for convenience and for protecting the steel from the weather. These reinforcing rods, like the hoop, must pass continuously around the silo, and where they are spliced they should be hooked and lapped as shown in Fig. 31.

The side pressure of silage against the silo wall was investigated a number of years ago by Prof. F. H. King of the University of Wisconsin and reported in the eighth annual report of the Wisconsin Agricultural Experiment Station. He found this pressure to amount to 11 pounds per square foot per foot of depth. Thus at a depth of 20 feet this bursting pressure amounts to 220 pounds per square foot. The silo should be made strong enough to withstand this pressure.

Plate I gives the steel required in cylindrical silos to carry

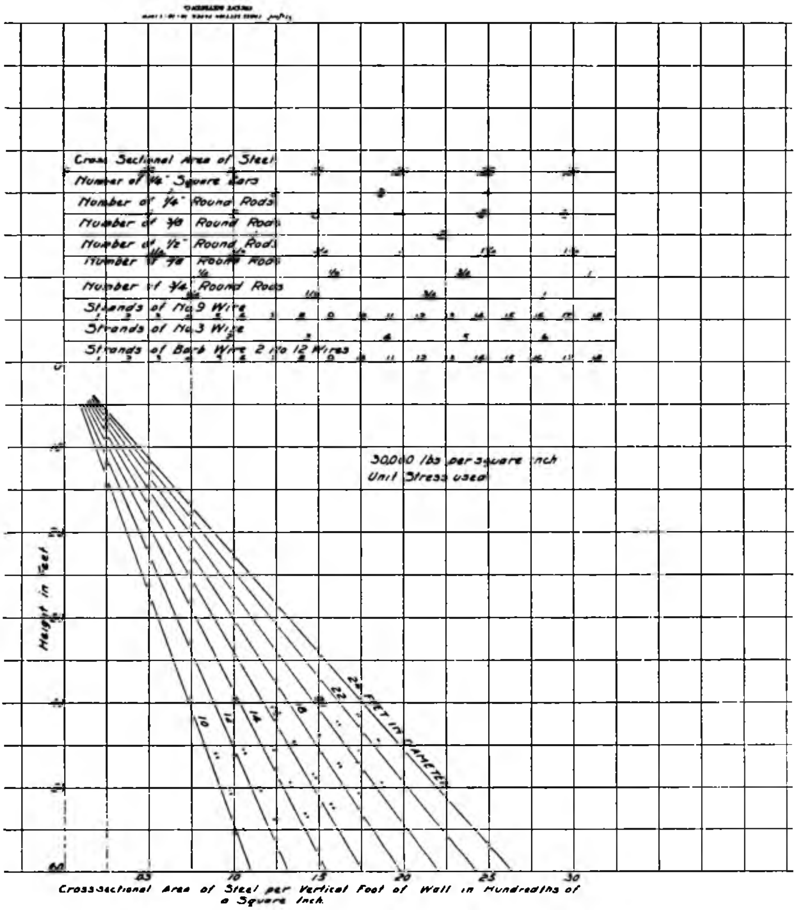


Plate I

a bursting pressure of 11 pounds per square foot per foot of depth and is based on a safe tensile stress of 30,000 pounds per square inch for the steel. The following example shows how Plate I is used: To find the amount of steel needed in a silo 12 feet in diameter at a depth of 30 feet from the top, find the figure 30 at the left margin and follow the horozintal line from there till it intersects the diagonal line marked "12 feet in diameter". From this point follow the vertical line down and find that .065 sq. in. is the cross sectional area of steel required per vertical foot of wall. The vertical line may be followed upward to find the number of hoops required per foot, thus three plus No. 9 wires, or one ¼ inch round rods.

The steel required at any depth may be found in a similar manner. It will be found that only a small amount of steel is needed at the top of the silo and that the amount needed gradually increases lower down in the wall.

THE ROOF.

A great many farmers are using silos without roofs and find them satisfactory. Snow in the winter usually melts as it strikes the silage and usually the moisture from snow and rain does not injure the silage.

On the other hand, a properly constructed roof has several advantages and is considered by many farmers to be well worth what it costs. Perhaps the greatest advantage of the roof is that it reduces the amount of freezing of silage. The roof is also valuable in protecting and strengthening the silo, in adding to its appearance, and in making it a more pleasant place to feed from in cold weather.

The silo roof should be firmly fastened to the wall to prevent the roof from being damaged by wind storms. The roof

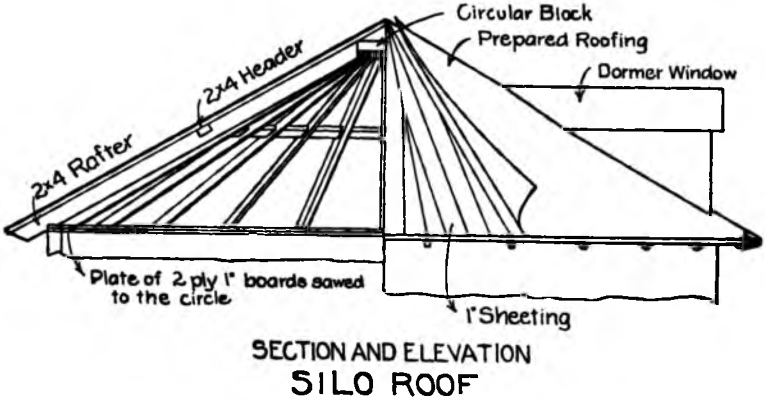


Fig. 6. Frame roof for a silo.

Fig. 7. False work and cornice block in place to receive sheeting.

should make a tight joint with the wall to prevent entrance of sparrows or pigeons and to prevent air circulation which would draw the warm air out of the silo.

A dormer or trap window must be placed in the roof to admit the elevator from the silage cutter. The dormer window is more convenient in placing the blower pipe, but is more expensive, especially in the masonry roof. This window should be glass to prevent air circulation and admit some light so that it will not always be necessary to use a lantern in removing silage.

Frame Roof. The framing for a silo roof is shown in Fig. 6. The sheeting is sawed into triangular pieces diagonally across the board and both ends used, so that there is very little waste. The sheeting may be covered with shingles or prepared roofing. The latter will make a roof more nearly air tight and is quite satisfactory when a good quality is used. Plain boards do not make a good roof.

Galvanized Steel Roofs. These may be purchased ready to attach to the silo. Some of these have the advantage of opening upward from the center so that the roof panels form an extension of the silo wall while filling. This adds a little to the capacity of the silo. As a rule, the steel roof does not fit closely to the wall.

The Concrete Roof. To build a concrete roof, it is necessary first to construct false work to support the concrete un-

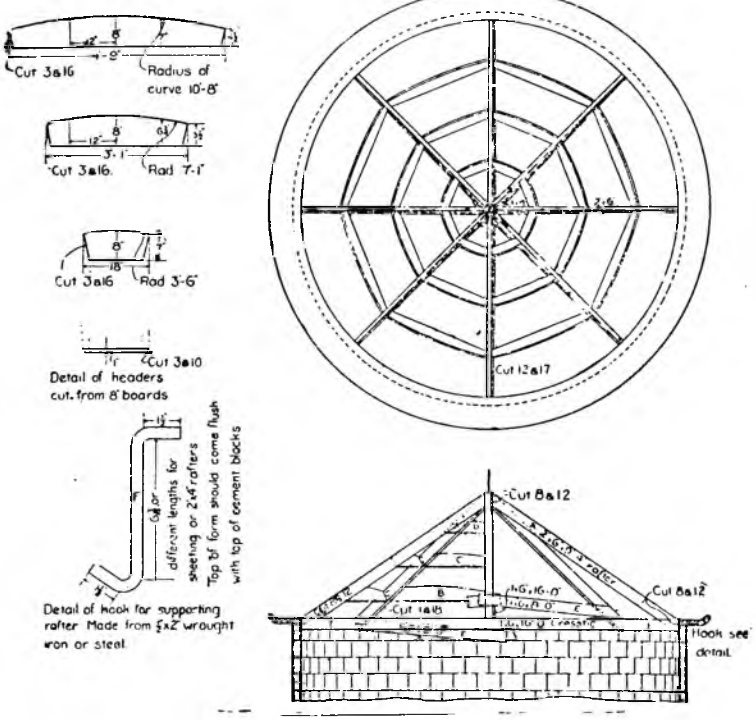


Fig. 8. Falsework for concrete roof.

til it sets. This false work as shown in Figs. 7, 8 and 9 is similar to the frame roof. The rafters are supported on hooks at the wall as shown clearly in Fig. 9, so that the false work may be removed after the concrete has set. Each rafter end must be securely tied to the center post to prevent any outward pressure on the wall.

The concrete roof should have a thickness of three inches near the lower edge tapering to a thickness of two and one-half inches at the peak. The mixture should be one part cement to two and one-half parts clean coarse sand. To this may be added two parts of screened gravel, the particles being from one-fourth inch to three-fourths inch in diameter. The concrete should be reinforced as follows for a 16 foot silo: A ½x½ inch square twisted steel bar embedded in the concrete at the base of the roof directly over the wall and extending continuously around the silo with ends of the bar either hooked or else lapped at least two feet. This reinforcing resists the outward pressure due to the weight of the roof. In addition to this a black wire mesh reinforcing should be used in the roof.

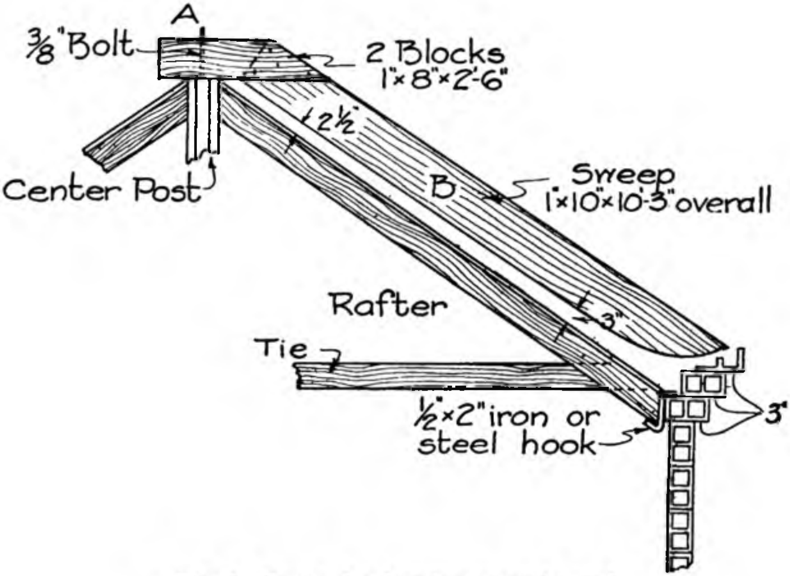


Fig. 9. Sweep for forming concrete roof.

In placing the concrete it is advantageous to have an accurate guide for striking off the surface to the proper thickness. This is shown in Fig. 9. The board "B" is fastened so as to swing on the bolt "A" in the center post.

The trap window is made with a tapered form made of 2x6's as shown in Fig. 10. This is set on the false work for the roof before the concrete is placed.

The roofs of the first Iowa silos built by the Agricultural Engineering Section had the cornice made of cement blocks as shown in Fig. 8. It was found later that the cornice could be more easily constructed of clay blocks as shown in Fig. 9. The blocks for the upper course are split, forming "L" shaped pieces which are filled with concrete. For a concrete silo a cement cornice block may be used.

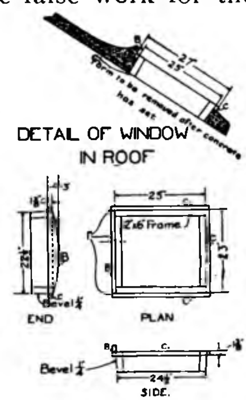


Fig. 10. Detail of form for window.

DOORS.

The silo door should form an air-tight joint with the door frame and be flush and smooth on the inside. It should be of a size convenient for persons to enter the silo and for throwing out the silage.

For wood stave silos the doors are supplied ready made by the silo manufacturer. For masonry silos the doors are usually made on the job or in a local shop. Fig. 11 shows a door made of two thicknesses of flooring crossed with tar paper between. These doors are beveled at the sides to fit the beveled shoulder in the door jamb, leaving room for the clay which is used in sealing these joints.

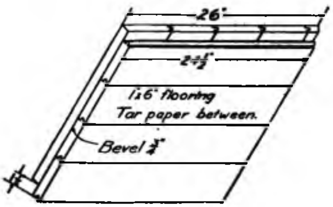


Fig. 11. One type of continuous door.

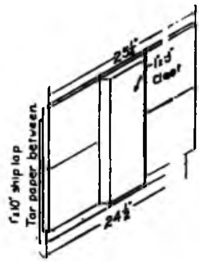


Fig. 12. A cheaper type of continuous door.

A cheaper and very good door is shown in Fig. 12. This is made of two thicknesses of shiplap with tar paper between. A 1"x8" cleat is used on the inner side of the door.

To prevent spoiled silage around the doors it is necessary that the joints between doors and door frames be air tight. The joints may be made tight by sealing with clay, or where clay is not available oil meal may be used. A quantity of fine clay is mixed with water to the consistency of putty. The shoulder in the door frame is filled with this before pressing the door into place. If the mud is rather stiff it will hold the door in place until the silage is up high enough to cover it. The door is then held firmly in position by the pressure of the silage.

A great many builders prefer to use a clamp to hold the door in place. This may be accomplished by placing a 2x4 across the outside of the door frame at the middle of the door. Then use a bolt through the center of the door and through the cross piece and draw up tight with nut.

THE CHUTE.

A chute to enclose the doors is a necessity. It prevents blowing and scattering of silage when thrown out from doors. It may be of light wooden construction, but should be securely fastened to the silo. For a masonry silo, a masonry chute presents a better appearance and is more substantial.

Fig. 13. A silo which was not properly anchored, after a storm.

Galvanized steel chutes present a good appearance and should be durable but they are expensive under present conditions.

It is desirable to have a window near the top of the chute to provide light for the ladder at the silo doors.

ANCHORING SILOS.

Silos of wooden construction are light and if exposed to high winds should be anchored securely. Anchor bolts should be placed in the foundation. Guy wires or cables should also extend from near the top of the silo to "dead men" or anchor posts at some little distance from the silo. These guy wires or cables should be provided with turn-buckles so that they can be easily tightened if they become slack.

VENTILATION.

When fresh silage is placed in the silo a small quantity of carbon dioxide may be formed at the surface due to fermentation. There is a case on record in which three men were asphyxiated by this gas when they entered the silo to continue filling after some fresh silage had been in the silo over night.

To prevent such accidents a door should be left out at the surface of the silage when it stands over night or for a longer period during filling. Because carbon dioxide is a little heavier than air it will then drain out down the chute.

In a pit silo, if silage is allowed to fall in for several minutes before the men enter, the carbon dioxide will be stirred up to such an extent that there will be no danger of asphyxiation. An additional precaution would be to lower a lighted lantern into the silo. If carbon dioxide is present in a dangerous amount it will put out the light.

A ventilator in a silo roof is of no practical value whatever. During cold weather it is best to prevent circulation of air above the silage in order to reduce freezing.

FILLING.

Best results are obtained where the silage is uniformly distributed thruout the silo and is carefully packed by tramping. Special care should be used in packing the silage near the walls and around the doors.

The weight of the silage is not sufficient to force the air out without the aid of tramping. Care should be taken that the heavy and light portions of the silage remain uniformly mixed. When the silage is dry, water should be added in sufficient quantities to cause the silage to settle well and to exclude the air.

Unless feeding begins at once after the silo is filled, a layer of silage at the top will spoil. To avoid undue loss it is well to remove the ears from the last load or two of corn put into the silo. This may be done in the field before the corn is cut or it may be done as the corn is unloaded into the cutter.

PART III—TYPES OF SILOS.

A discussion of the construction and use of the types of silos most common in Iowa is taken up in the following pages. For a discussion of the construction of foundations, floors, roofs and other parts see Part II of this bulletin. Silos may be classified as wooden and masonry.

WOODEN SILOS.

Wood has always been the material most extensively used in farm building construction in this country. When set on a foundation running well above ground the ordinary wooden construction is reasonably durable for most buildings. Wood has not, however, proved as generally satisfactory and durable for the construction of silos as for other farm buildings. The principal difficulty experienced has been in protecting the wooden silo from damage by wind storm. If a wooden silo is successfully protected from damage by wind and a high grade wood is used the silo will preserve the silage in a satisfactory manner and should give service for from 10 to 25 years. Several types of wooden silos have proved successful.

THE WOODEN STAVE SILO.

The great majority of wooden silos in use are stave silos and this type has proved to be generally successful.

The measure of success depends largely upon method of construction, material used, and care taken of the silo. If

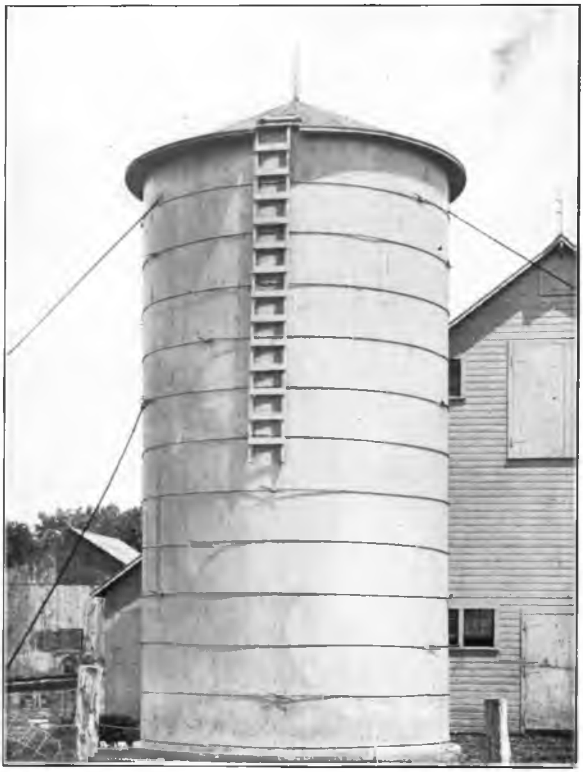


Fig. 14. A Stave Silo. Note the guy wires which are properly located.

properly constructed, the stave silo incorporates the essential features and many of the desirable features discussed in Part I of this bulletin.

If staves are of high grade material, well tongued and grooved and the hoops kept tight, the walls are necessarily tight, smooth and rigid and the doors are fully as tight and as convenient as in any other type of silo.

Investigation indicates that the life of a stave silo varies from less than five years to more than 25 years in some instances, depending upon the quality of the material used in the silo and the care given to it.

Lumber for Stave Silo. In the purchase of a stave silo, the kind and grade of lumber is of the greatest importance. Badly cross-grained lumber or any containing heart or wind shake, sap, or bark should be discarded. To have an opportunity to sort the lumber the silo should be ordered early and an early delivery insured so that if any poor staves are received they may be discarded and new ones secured to replace them, even if it be entirely at the purchaser's expense. A poor stave should never be put in a silo, as it lowers the value of the entire structure.

Redwood is one of the conifers which is generally accepted as having the best qualities of any wood used in silo construction. Redwood trees are very large and the lumber uniform. In buying redwood silos, a very good grade of practically clear staves may be secured. The shrinkage and swelling due to moisture is less than in other woods. This is quite an advantage on account of the shrinkage that occurs when the silo is empty.

Oregon fir is an excellent wood for stave silos, and it has usually been possible to secure it in full length staves and in quite clear and uniform grade. With reasonable care and a foundation high enough to raise it above moisture, a silo with fir staves should last for a long term of years.

Cypress is well adapted to the construction of silos. Only clear or good sound stock should be used. More cypress than any other kind of wood is used for water tanks in the middle west. Cypress is one of our most durable woods. Its chief disadvantage is a large amount of shrinkage.

Tamarack or larch is very similar to the best hard pine, but where equal grades of each are obtainable it is slightly preferable on account of its greater durability.

White pine, if free from loose or large knots, makes a good silo. The staves cannot usually be obtained in full length staves for a desirable height of silo.

Long leaf yellow or **hard pine** is the strongest and stiffest of all pines and if a choice grade is secured, it makes a good silo at a reasonable price. It shrinks a little more than some of the woods previously mentioned, but the hoops of any stave silo should be tightened when the silo is empty.

Fig. 15. Erecting a stave silo.

There are a large number of silo manufacturers making stave silos, many of them having some patented features. They differ in the details of doors, door frame, roof and anchoring devices. They all use staves about two inches by six inches with dressed and matched edges One recognized advantage of the commercial stave silo is that it comes complete including hoops. door frames, doors, door fasteners and anchoring devices. It can be erected in a short time by carpenters or by farm help.

Fig. 15 shows scaffolding for erecting a stave silo. For a fourteen foot silo the scaffold will have seven upright members placed on a circle about three feet outside of the foundation. These are securely braced together and provided with supports for run boards at intervals of seven or eight feet vertically.

Creosoting. Recently the practice of creosoting silo staves of the less durable woods has come into practice. It has been demonstrated that such treatment of posts and railroad ties prolongs the life of the wood materially, and in the case of the softer and less durable woods is well worth the expense.

There are at least three treatments in use, painting, dipping in heated creosote, and dipping in heated creosote under pressure. Brushing is the least effective of all and the pressure system the most effective, although little practiced. The value of the treatment will depend upon the depth of the pentration of the creosote. In addition to prolonging the life of the wood, the treatment reduces the absorption of the wood and thereby reduces the shrinkage during dry weather.

The Animal Husbandry Section has reports of a number of cases in which creosote paint has flavored the silage to a distance as great as 18 inches from the wall. This paint was applied to the interior of wood stave silos shortly before filling. In some cases the creosote flavor was so strong that animals would not eat the silage from near the wall.

An examination of the silage in a number of commercial creosoted stave silos has been made and any creosote flavor in silage from this type of silo has never been found or reported.

Care of the Stave Silo. The life of the silo will depend largely upon care taken in keeping the hoops at proper tension, keeping the silo well painted and preventing the collection of refuse about the bottom of the staves, which will keep them moist and thus promote decay. In keeping the hoops tight the owner should frequently, at least after emptying and during any continued dry or wet weather, tighten the hoops if they are not tight. If they are tight they should be loosened and then tightened again to be sure they are not too tight, for if too tight the wood fibre will be crushed, causing rapid decay.

MODIFIED STAVE SILO.

This silo consists of the ordinary wood stave covered with thin matched siding placed horizontally. The siding takes the place of the hoops and protects the staves from weather. Insulating material may be used between the staves and the siding to serve as a protection against weather. By the use of this siding one may reclaim or rebuild an old wood stave silo and lengthen its life many years.

THE PANEL SILO.

This silo consists of a number of vertical panels about two feet in width, set in a position to form a regular polygon approaching the circle. These panels are built up of vertical ribs and horizontal matched paneling between ribs. Steel hoops are placed about the ribs, and as the hoops are drawn up the ribs are compressed and the paneling locked in place. The panel silo may be secured in either the single or double wall.

THE WOODEN HOOP SILO.

The wooden hoop silo has been extensively used in the eastern part of the country for several years. This type is quite rigid, does not require attention during the summer months to keep the hoops tight, and when made of good material should be as durable as any wooden silo. The wooden hoops may be made of several thicknesses of beveled weather boarding or other lumber ½-inch thick bent to a circle and thoroly nailed. These hoops are easily made by first preparing a circular form which will enable the boards to be bent into shape and held while nailed. This form is made by bending boards to a circle, forming a hoop, with an inside diameter equal to outside diameter of the silo hoops, or by nailing blocks around a circle of this diameter on a wooden floor or platform. These wooden hoops are spaced above one another at intervals of about 3 feet and lined on the inside and covered on the outside with a good grade of flooring.

Fig. 16. A wooden hoop silo under construction.

Fig. 17. The wooden hoop silo completed.

A wooden hoop silo was built in 1912, under the supervision of J. B. Davidson and M. L. King of the Agricultural Engineering Section. This silo was similar to one built at Scottsville, N. Y., in 1894, which was examined and found in good condition during the spring of 1912. The hoops in the silo built by the Agricultural Engineering Section were made up of 8-ply of 4-inch redwood siding. The design was original in the braces between the hoops, as shown in figs. 16 and 18. This type of bracing supports the hoops rigidly in plumb position. The hoops serve to support run boards, and therefore no scaffolding is required in erecting this silo. The inside of the silo was made of a good grade of white pine flooring and the outside was covered with yellow pine flooring.

The bill of material and total cost of this silo, including excavation, roof and chute, was as follows, in 1912:

COST OF WOODEN HOOP SILO IN 1912.

Size 12 feet diameter by 32 feet high.

Excavation—	
3′ deep, 12.6′ diam.=375 cu. ft. at 1½c	$ 5.65
Foundation—	
5′ deep, .5′ wide, 12′ diam.=105 cu. ft. concrete—105 cu. ft.=3.9 cu. yds. at $9.00	35.10
Hoops—Redwood siding 4″—	
1200 feet siding at $30.00 per M	36.00
Braces between hoops—	
350 feet 2x4 at $30 per M	10.50
Inside walls—	
1300 feet 1x6 at $50 per M	65.00
Outside walls—	
1500 feet 1x4 at $25 per M	37.50
Roof—1-3 pitch—	
8 rafters—56 ft. 2x4 at $30 per M	1.68
16 headers—28 ft. 2x6 at $30 per M	.84
175 ft. 1x12 sheeting at $32 per M	5.60
1 roll prepared roofing—2 ply	3.00
1 window sash	.50
Chute—	
253 ft. 1x12 at $32 per M	8.10
2 window sashes at 50c	1.00
240 ft. 2x4 at $30 per M	7.20
Hardware—	
12 bolts for foundation 12″x½″	.30
10 bolts for doors 8″x½″	.20
150 ft. guy wire at 4c ft.	6.00
4 turn buckles at 25c each	1.00
16 wire clips at 12.5c each	2.00
Nails	2.65
Labor	25.00
Total Cost	$254.82

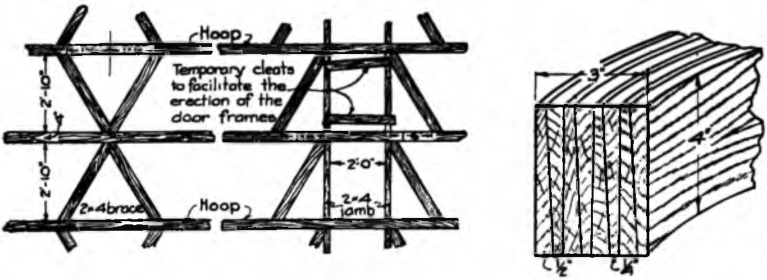


Fig. 18. Details of the wooden hoop silo.

At 1919 prices, this silo would cost about $400.00.

This silo was examined in July, 1918. The owner stated that it had given excellent service. The interior of the silo was found in good condition. The siding on the outside of the silo showed some weathering. The writers would recommend either using a better grade of flooring outside or else leaving this outside covering off entirely. If this is left off, the top of each hoop should be protected with a coating of tar.

This is a very good type of "home made" silo since all the materials may be purchased locally and the silo may be erected by carpenters and farm help.

MASONRY SILOS.

In recent years masonry has come into extensive use for the construction of silos. There are a number of types of masonry silos each of which, if properly constructed, has the essential features and most of the desirable features discussed in Part I of this bulletin. As compared with wooden silos, masonry silos have the advantage of being more durable, being fireproof, being proof against damage by ordinary wind storms, and in requiring less labor and expense for upkeep.

Competitors have raised the following arguments against masonry silos: (1) that walls are porous and permit a transfer of moisture and air which causes the silage to spoil next to the wall, (2) that silage freezes worse in the masonry than in the wooden silo, (3) that cement neutralizes the acidity of the silage and that this acid works on the cement and causes the surface of the wall to soften, (4) that masonry walls crack due to the bursting pressure of the silage. These arguments may be answered as follows:

(1) Porosity of walls. Masonry walls should be built of hard burned building block or brick, or of a dense mixture of concrete and may be further perfected by applying a wash to the inner surface of the wall. A properly constructed masonry silo wall is sufficiently impervious that the silage will keep as well as in the wooden silo.

(2) **Freezing of Silage.** Temperature records of the silage in three silos (wood-stave, monolithic concrete, and Iowa silo) at the Iowa State College for four years show that there is so little difference in temperature at the inner surface of the north wall that the wall construction can have very little effect on the amount of freezing.

(3) **Action of Silage Acid on Concrete.** After a concrete silo has been used for one year or more, a thin layer of chalky substance will usually be found on the inner surface of the wall. This substance is formed by the action of silage acid on cement. The surface is affected to a greater depth with a poor quality of concrete than with a good, dense concrete. No protective coating has yet been found which will entirely prevent the action of the silage acid on the cement.

The Agricultural Engineering Section has reports on a large number of concrete silos which have been in use for from one to 15 years. Several of these silos have been in use more than ten years and in no case has the silage acid done enough damage to the walls to cause the owner to feel concerned about it.

(4) **Cracking of Walls.** There are some cases on record in which masonry silo walls failed, due to the bursting pressure of silage. This may in every case be attributed to incorrect reinforcing of walls or door frames. Our recommendations for reinforcing the walls will be found in Part II of this bulletin. A description of the reinforced concrete door frame will be found in the discussion of the Iowa silo.

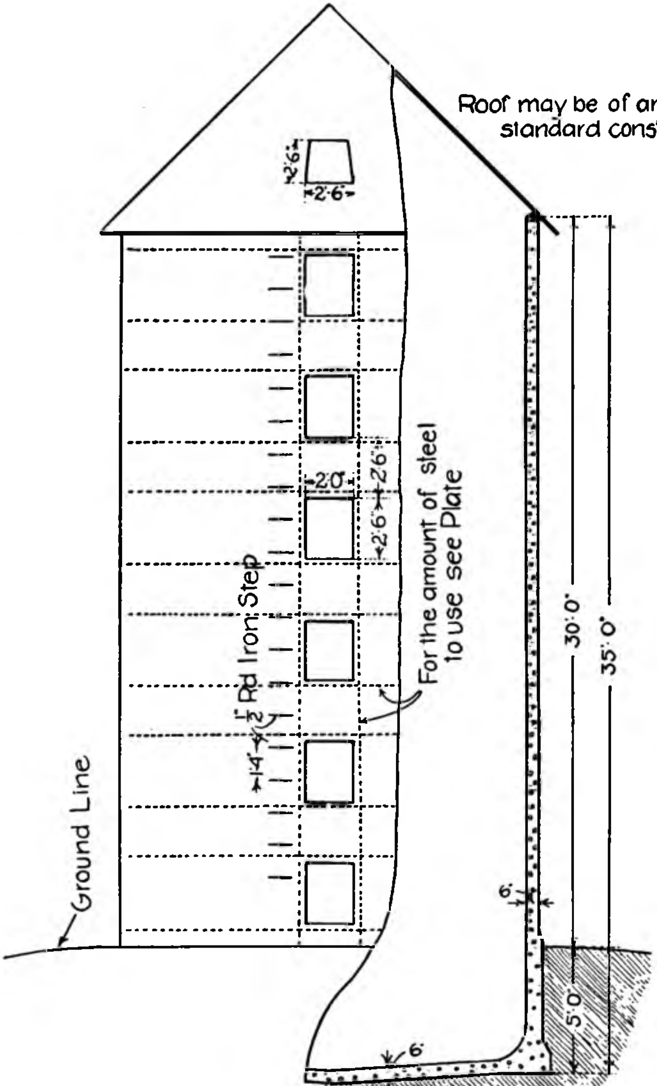
THE MONOLITHIC CONCRETE SILO.

This silo has a solid reinforced concrete wall, usually six inches thick, as illustrated in Figs. 19 and 20. Investigation shows that this type of silo, when properly constructed, preserves the silage in a satisfactory manner and that it is one of the most durable silos on the market.

It is not advisable for a man who has had no previous experience in concrete construction to attempt the building of a concrete silo. One who has had successful experience in constructing other buildings of concrete should be able, by giving some study to construction details, to build a good concrete silo. To make the silo durable, it is necessary that only first class work be done in every detail of construction.

Mixing and placing the concrete. Only a first class portland cement which has been stored in a dry place should be used.

The sand and pebbles should be clean, that is, free from clay, loam, and vegetable matter, and should be made up of only hard particles. The sand should be a mixture of large and



ELEVATION AND SECTION
CONCRETE SILO
Scale 5 Ft.

Fig. 19. Monolithic or Solid Concrete Silo.

small particles but should be a coarse sand. A fine sand is not suitable for concrete.

The mixture should be rich; that is, one part cement to two or two and one-half parts of sand. Four parts of screened gravel or crushed rock running from one-fourth inch to one and one-half inches should be added to the above mixture. This will make the concrete cheaper and not reduce its strength.

If bank run gravel is to be used, it sould be screened over a one-fourth inch horizontal or a three-eights inch inclined screen to determine the amount of cement needed. The material which goes thru this screen is sand and should be mixed with cement in the proportions stated above.

Another essential of good concrete is thoro mixing. The whole should be so thoroly mixed that there will be a coating of cement over each particle of inert material.

Enough water should be added to make a mixture which will quiver when tamped. This is sufficiently fluid that it can be worked into the corners of the forms and around the steel reinforcing and not leave air spaces. A wetter mixture does not give as dense a concrete, and furthermore, with a sloppy mixture there is a tendency for the coarse gravel to settle in spots leaving the sand and cement in other spots in the wall unless extreme care is used in placing it in the forms.

Fig. 20. A concrete silo under construction, using factory made steel forms.

In placing the concrete in the forms each bucketful should be dumped from directly above the place where it is to be in the wall. Dumping a large quantity in one place and allowing it to run to the sides increases the tendency for coarse and fine material to separate.

The concrete must be worked into place so as to leave no air spaces. The coarse particles should be worked away from the forms by spading.

In adding to the work of the previous day it should be first thoroly wet and sprinkled with cement, and then two inches of freshly mixed concrete put in place and stirred to bring the finer material into close contact with the hardened concrete.

Poor concrete is due in many cases to lack of moisture during the curing period. To properly cure concrete it is necessary to keep the wall moist for several days after the concrete is placed.

Reinforcement. The amount of circular reinforcement required for different heights and diameters is indicated in Plate I. Bars, rods, or wire may be used so long as sufficient cross section of steel is provided. The cross sectional area of steel extending across the doorway should be at least as great as that in any part of the silo. Vertical reinforcing is not absolutely necessary except at either side of the doorway; but it is convenient to use enough vertical rods in the silo wall to hold the horizontal reinforcement in place while the forms are being filled with concrete. A black woven wire reinforcing is sometimes used. This is similar to woven wire fencing except that strands are spaced equally distant in it, and are all the same size, and the horizontal strands are not crimped.

Fig. 21. Home-made forms for concrete silo.

For fencing, the horizontal strands are usually crimped to give some elasticity. This would not be desirable for steel reinforcement.

Forms. Silo forms may be made of wood or steel or wood covered with steel. The steel forms are most satisfactory since they give a smooth finish to the wall and are fairly light and convenient to raise. They are usually factory made.

There are several types of home made forms. Any Iowa farmer or contractor who is considering the building of home made silo forms may secure plans and bill of material from the Agricultural Engineering Section.

THE CONCRETE BLOCK SILO.

Some silos of this type are built with hollow concrete blocks similar to the blocks used for other buildings. The steel reinforcement is placed in the mortar joints. If a good quality of block is used and the mortar joints are carefully made, this is a good durable silo. It has the advantage over the monolithic concrete silo that no forms are required for the erection of the silo. A great amount of labor is involved in making and curing the blocks and in laying up the wall. In some cases the blocks are constructed at the building site, but in recent years the blocks are mostly made in the plant and shipped to the builder.

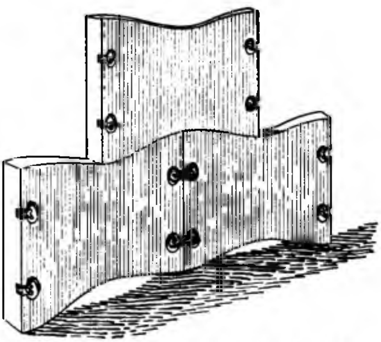


Fig. 22. Solid concrete blocks.

Solid Concrete Blocks are now used for silo construction which have steel reinforcing running through the block. This steel is exposed and bent at the ends of the block so it may be fastened to the steel of adjoining blocks by means of a clip or link. These exposed ends and fasteners are plastered over with cement mortar, leaving the wall smooth and all steel embedded in concrete. These blocks are accurately molded and fit together in the wall so that no mortar joint is required. The joints are sealed by applying a cement wash as explained in discussion of the concrete stave silo on page 127. This type of silo is used in some communities of Iowa and adjoining states.

Fig. 22 shows an example of the solid concrete block. This block is 3 inches thick, 14 inches high and about 21 inches long, and contains two ⅜-inch steel rods spaced 7 inches on center.

THE CONCRETE STAVE SILO

This silo is built of staves twenty-eight or thirty inches long, ten inches wide and two and one-half inches thick. The staves are held in the wall by steel hoops. The joints between staves are made tight by a close fit and by washing the inner surface with cement after the wall has been erected.

Fig. 23. A group of concrete stave silos of "double hooped" stave shown at "a" Fig. 24.

The first concrete stave silo was built in March, 1904, at Cassopolis, Michigan. It was reported to us in 1918 to be still in use and in good condition. A few of this type of silo were built in Iowa six or seven years ago. It is now a very popular silo in some localities.

The writers have recently inspected a large number of these silos in different parts of Iowa, and have found that they are giving general satisfaction. One silo was found which did not stand plumb and some silos were found in which there were a number of cracked staves. The silo out of plumb is an example of poor workmanship in erecting. While the erection of this silo does not require highly skilled labor, the work should be superintended by a careful and experienced man. Cracked staves have not in any case investigated caused unsatisfactory service from the silo. A cracked stave, however, represents a weakness. It is due to either (1) a poor quality of concrete in the stave, or (2) that the stave is warped a little and cracks when it is placed in the wall and the hoops are tightened, or (3) that the hoops are placed too far apart.

The staves used in the original concrete stave silos were book shaped. This stave is shown in Fig. 23, and in "a" Fig. 24. The interlocking end joint stave is shown in "b" Fig. 24 and in Fig. 25. Fig. 24 also shows a step joint stave "c" and at "d" a stave with both edges concave. The hollow joint made by setting the type "d" staves is filled with cement mortar. There are other concrete staves on the market which differ slightly from those described above.

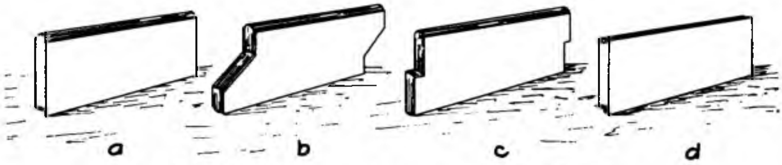


Fig. 24. Concrete staves common in Iowa.

This silo has a much thinner wall than any other type of masonry silo and therefore it is especially important that the staves be made of first class concrete. To secure a good concrete stave, it is necessary to use a rather rich mixture of cement and good clean coarse sand. Concrete staves are made by two methods—the dry mixture and the wet mixture. By the dry mixture method the staves are made in a machine mold from which the stave is removed on a pallet immediately after the mixture has been rammed into place and surface smoothed. The mixture should be as wet as possible and still have the stave hold its shape as it comes from the mold.

When using the wet mixture method the concrete is wet enough to be "quaky." The stave must be left in the mold until the cement has hardened. Proper curing is especially important. Staves should be protected from the sun and sprinkled at least three times a day for a week. After that they do not need as much care, but should be cured for a month.

The writers believe that except possibly for small silos, it is advisable to "double hoop" the concrete stave silo, that is to have hoops at the ends and at the middle of each stave. When a rich mixture was used for the staves, "single hooping" (that is, placing the hoops twenty-eight or thirty inches apart) has proved satisfactory on silos as large as twelve feet by thirty-two feet. From the standpoint of strength of construction it would be better, however, to use smaller hoops placed closer together. The method of fastening hoops at the door is shown in Fig. 25.

Since there is no shrinkage of the staves it is not necessary to adjust the tightness of hoops after the silo is erected. Since concrete and steel expand the same due to heat, there is no loosening of hoops due to warm weather. The hoops are exposed to the weather, and altho it is not customary to do so, it would no doubt pay in the long run to keep them painted. This would also improve the appearance of the silo. Experience has shown that it pays to keep steel railway and highway bridges painted, and this is probably also true for steel hoops on silos.

Fig. 25. Showing interlocking staves and method of fastening hoop at door.

The sealing of the joints to make the silo air-tight is a feature which requires care and experience. The water-proofing or inside wash is applied as soon as the walls and roof are completed, and the scaffolding is taken down. First, thoroly flush wall with clean water to remove all dirt particles and fill pores of staves so a good bond is secured. Mix the water-proofing to a cream paste and apply to vertical and end joints with a stiff broom until joints are filled. Another man follows, applying the waterproofing with a white wash brush or broom using an up and down stroke.

The waterproofing wash used is a portland cement paste to which some builders add other materials. One contractor, some of whose silos were inspected, uses one-half pound of lye and one pound alum to eight gallons of cement paste. Another contractor uses two pounds of patent waterproofing to one hundred pounds of cement and secures excellent results. Others use a pure cement wash with good results.

From the contractor's standpoint the concrete stave silo has the advantage that the labor of making the staves may be done during the spring and only a small amount of labor of erecting the silo is left to do on the farm during the summer season when most silos are purchased.

THE IOWA SILO.

Bulletin No. 100 issued in 1908 and reissued in 1909 presented a design of a silo using hollow clay building blocks for the walls. After experimenting with the construction of this type of silo the design was presented in detail in 1910 in Bulletin No. 117. It is estimated that 500 of these silos were built in 1911 and 1,000 in 1912 and it has now become one of the most popular types of silo in this state.

When properly constructed the Iowa silo has walls which are strong, smooth and impervious, insuring the proper preservation of the silage. The material should insure a durable silo requiring the minimum attention for care and repair. It is fire proof and not damaged by ordinary wind storms. The silo is of reasonable cost, being capable of erection without expensive forms or elaborate scaffolding. The material used in construction can be obtained generally thruout Iowa.

The wall of the Iowa Silo is constructed of hollow clay building blocks reinforced with No. 3 or 9 unannealed wire placed in the mortar joints. The same construction, however, is adapted to any block material such as concrete blocks or brick.

Various sizes of blocks have been used in the construction of the wall but 4x8x12 inch or 5x8x12 inch blocks laid on edge, making four or five inch wall, seem to be the most satisfactory sizes.

Fig. 26. The first Iowa silo built at Ames.

Fig. 27. Hollow clay blocks for Iowa Silo.

The four inch wall is easier to lay than the five inch wall, and experience has shown that the four inch wall has all the strength needed. It is very important that the blocks be properly curved so as to insure a smooth wall on inside when laid in place.

Quality of Material. In clay blocks there are many grades. These variations in quality are due mainly to three causes, quality of raw material, method of burning, and defects in forming.

Brick clays are made up principally of two classes of material, one that melts at temperatures usually secured in the hottest portions of the brick kilns, and one that remains firm at these same temperatures. Proper portions of each of these classes of material are essential. The former called the fluxing material melts and binds together particles of the latter, while the latter preserves the desired form of the brick or block thruout the burning process. It will be readily seen that as the fluxing material fuses it will fill all of the space between the other particles, and upon extreme heating it flows out over the surface giving it a glassy appearance. This process is known as vitrification.

In the manufacture of the blocks, on account of their being made up entirely with thin walls, it is necessary to use a clay which is comparatively low in fluxing material in order that the blocks will hold their shape well during the burning. Thus it will be seen that completely vitrified blocks are not usually made, but good semi-vitrified blocks are sufficiently dense to be extremely durable and are usually well shaped.

To make them appear hard burned and present a glassy surface to the weather, clay products are sometimes treated externally with salt which, when burned, causes the block to have a glassy surface. It is evident that such treatment, though protecting the block to a certain extent, affects only the surface. The advantage of such a surface, however, is not sufficient to compensate for its interference with the detection of soft or porous blocks.

In some clays are found pebbles of limestone. The pebbles after burning absorb moisture, slake, swell and chip particles off the block. This defect is serious and blocks extensively affected thus should not be used.

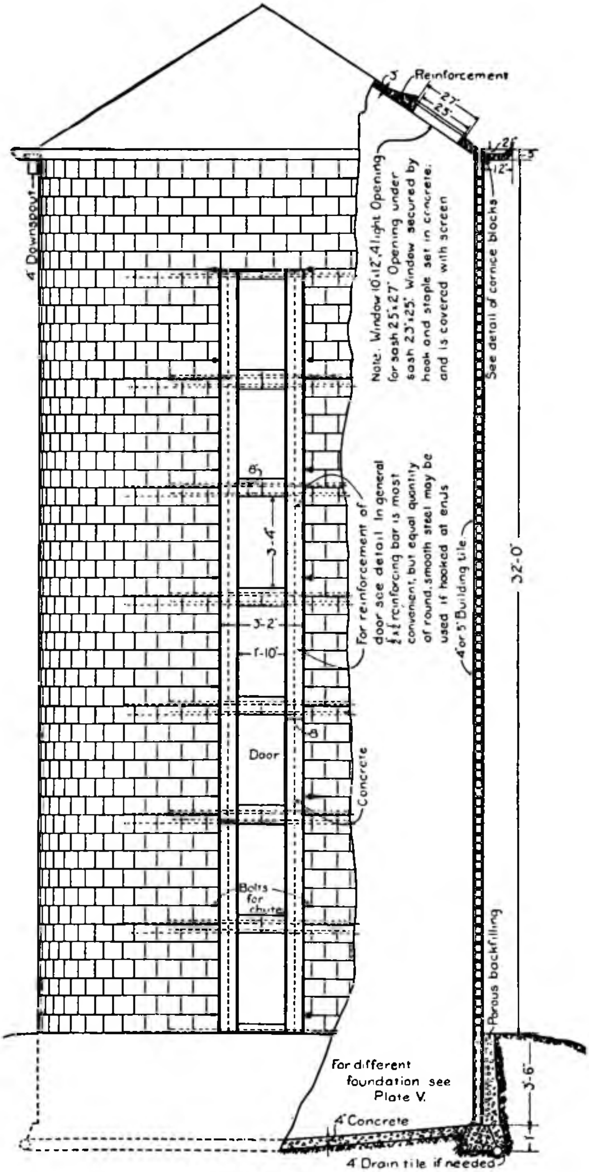
Fig. 28. An Iowa Silo with improved cornice.

In forcing some clays thru the die, parts separated by the auger do not properly unite again. The result is stratified or grained appearance of the fractured end of a block which should show dense uniform material.

Frequently otherwise good blocks have a slight check in one of the outer walls. If this occurs at either end, a small amount of mortar may be placed inside of the block covering the check. However, a block should be discarded if such check is large enough to materially weaken it.

In all kilns the blocks nearest the fire become burned harder than the other blocks and in any kiln only a portion of the blocks will be fit for silo construction. For this reason silo builders should not expect to secure such blocks at less than standard prices plus a reasonable price for sorting.

Dangers of Inferior Blocks. The greatest danger from inferior material is the liability to disintegrate due to the action of frost while wet. The Agricultural Engineering Section has a report on a silo of this type which, due to distintegration of blocks, had to be torn down after ten years service. It will be readily seen that this action only affects porous blocks as



ELEVATION AND SECTION
IOWA SILO

Scale 5 Ft Continuous door

Plate II

no appreciable amount of water gets into the dense blocks. In case the openings in a porous block are filled with water and exposed to freezing temperatures, the material surrounding the pores will crack open by the expansion of the water by freezing. Some clays appear to have a greater elasticity or toughness. Therefore, they are able, even though porous, to withstand this action somewhat more successfully than others.

The most general and reliable test which can ordinarily be applied to this material is a determination of the percentage of moisture that a block will absorb. Such a test is quite easily made and in case the quality of material is questionable, the purchaser of these blocks may well afford to use this test. The following specifications have been drawn to cover the quality of hollow clay silo blocks.

These specifications have been prepared with a view of assisting those manufacturing or purchasing hollow clay building blocks for the construction of the Iowa silo as described in this bulletin. These specifications may be made a part of the contract in purchasing silo blocks.

Dimensions. All the walls of the blocks shall be not less than five-eighths (5/8) of one inch in thickness and shall have a fillet of not less than one-fourth (1/4) of an inch radius in each inner corner. If this fillet is not provided, the walls of the block shall be at least three-fourths (3/4) of one inch thick.

Strength. Blocks must have a crushing strength of 120,000 pounds per square foot when tested on edge or the way blocks are to be laid in the silo wall. The crushing strength of the material of the block walls shall be not less than 2,500 pounds per square inch.

Soundness. All blocks shall be free from cracks extending thru the walls at any place thruout their length. All blocks shall give a clear ring when held in the hand and struck with a light hammer.

Burning. All blocks are to be hard burned and shall show a uniformly dense structure thruout, being free from laminations.

Absorption. Blocks shall not absorb more than seven per cent of their dry weight of water in the 72 hour immersion test. In making the absorption test at least three blocks shall be tested which shall be placed in a drying oven and maintained at a temperature of 212 degrees F. or greater for 24 hours or until they no longer lose weight. The blocks should be allowed to come to room temperature and carefully weighed. Then the blocks are to be immersed in rain water for 72 hours or until they no longer gain weight. Upon removing the block from water it should be wiped dry and again carefully weighed. The increase in weight shall be considered the absorption and shall be divided by the dry weight to give the per cent of obsorption.

The scales or balance used shall be sensitive to one ounce when loaded with one tile 20 pounds and weighings shall be at least to the nearest ounce.

The boiling test for absorption may be made in place of the immersion test. This test shall be that used in standard specifications for drain tile adopted by the American Society for Testing Materials or briefly as follows:

The tile specimens shall be dried and weighed as explained above and shall be covered with rain water, raised to the boiling point and boiled for five hours and then allowed to cool to room temperature, dried and weighed. For the boiling test the blocks shall not absorb more than nine per cent of their dry weight.

Lime. All blocks shall be free from lime or chalk in the form of nodules and all blocks tested for absorption after the manner described shall be free from indications of chipping or spalling.

Curvature. No block shall vary on the concave side more than one-eight of an inch from the curvature of a circle of the same diameter of the inside of silo.

Mortar. The mortar used for this work is composed of cement, lime and sand. The sand should be medium fine. A certain amount of lime is necessary as cement mortar is not plastic enough to stick to the ends of the blocks when applied. No more lime should be used than necessary to make the mortar workable. The quantity of lime for this purpose will vary somewhat with the material and workman. Perhaps the least amount of lime which could be made to serve the purpose is one part of cement, one-third of one part of thoroly slacked lime and two parts of sand, while one part of cement, one part of lime, and four parts of sand is as much lime as would ever be required. The importance of measuring all materials and thoroly mixing them cannot be emphasized too strongly. Thoro mixing is absolutely essential for a smooth mortar. Very few men can make a uniform quality of mortar without measuring the materials.

In order that cement mortar may set properly it must contain considerable water. If this water is drawn out by coming in contact with hot, dry blocks, the mortar cannot harden properly. A hard block will of course absorb less moisture than a soft one but both hard and soft blocks, if warm, should be dipped for a few moments just before laying.

Reinforcements. The most convenient and advantageous place for the reinforcement in this type of a silo is in the mortar joints. The size of steel necessary is less than the thickness of the mortar joint; therefore, it does not interfere with the laying of the blocks and by placing it in the mortar joint, it is thoroly protected from rust. The amount of steel necessary is shown in Plate III and the size of wire most suitable will vary with the size of the silo and its availability. Heavy wires are not generally carried in stock and therefore a decision in regard to the size to be used should be made and the order placed at least a month before building.

The size of the wire most convenient to use is No. 3, which is one-fourth inch in diameter. This is as large as can be handled in the mortar joints conveniently, but it is not larger than necessary. Even with this size of wire it is necessary in the case of large silos, and eight-inch blocks, to place more than one wire in each mortar joint near the bottom. However, if convenient to purchase, it will sometimes be advantageous to purchase No. 6, 8 or 9 wire for the upper portion of the silo where less reinforcement is necessary. The wire when embedded in the mortar will not rust and therefore black wire should be used, as it is cheaper than galvanized and bonds better in the mortar. All wire should be stored in a dry place where it will not rust. The most desirable quality is hard or high carbon wire. Soft or medium wire is difficult to straighten and kinks badly in handling, thus causing considerable trouble. Hard or unannealed wire is as cheap as any, more convenient, and stronger. Because these heavy wires are wound in coils it becomes a very important problem to straighten them sufficiently to lay on the wall.

The most convenient method tried for straightening this wire is shown in Fig. 29, and may be described as follows: Secure or build a reel from which a coil of wire may be conveniently unwounded. Mount this reel upon a plank or platform where it will turn easily, then secure a short piece of gas pipe close to the reel as shown in Fig. 30.

Through this pipe draw the wire as it uncoils from the reel. The pipe should be so placed that its curvature will be the reverse of the curvature of the wire in the coil. At a convenient distance from the pipe, drive a stake, at which point the wires may be cut to their proper length. In order to determine this length easily, another stake may be driven to

Fig. 29. Showing method of straightening wire by drawing through a bent pipe.

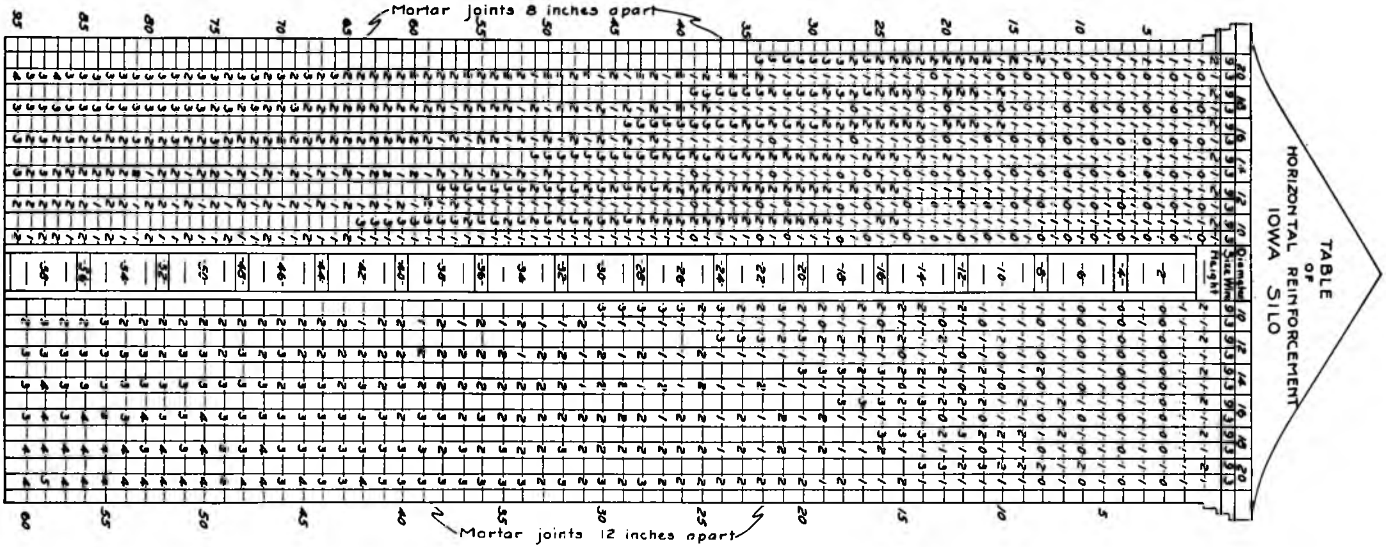


TABLE OF HORIZONTAL REINFORCEMENT IOWA SILO
Mortar joints 8 inches apart
Mortar joints 12 inches apart
Diameter
Size Wire
Height

Plate III

which the end of the wire may be pulled each time before cutting. As soon as the first wire is cut, it should be laid upon the wall or fitted to a similar sized circle to see if the curvature is correct. If not, the curvature of the pipe may be altered and, by a few trials, the proper curvature secured.

In Plate III is shown the number of wires number 9 or number 3, which should be placed in each mortar joint of any silo varying in diameter from 10 to 20 feet and 60 feet or less in height, with mortar joints 8 and 12 inches apart. The left half of the plate is for mortar joints placed 8 inches apart while the right half is for joints 12 inches apart. Most standard material is such as to be laid in one of these two ways. The top row of figures on either side of the plate indicates diameters. The left figure of the double column below each large figure indicates the number of number 9 wires, while the right of the double coulmn indicates the number of number 3 wires for each joint. The distance from top of silo should be the basis of calculation at all times.

In practice, the table would be used as follows: For example, take a 16x36 silo made of 4x8x12 blocks, reinforced with number 3 wire. In the left half of the table under 16 at a depth of 36 feet is found mortar joint number 55 which should contain two number 3 wires. Succeeding joints should be reinforced as indicated in this column successively above.

Laying the Blocks. The first course may be spaced around 1/8 to 1/4 of an inch apart without mortar in order to determine the proper diameter of silo and length of guide. This

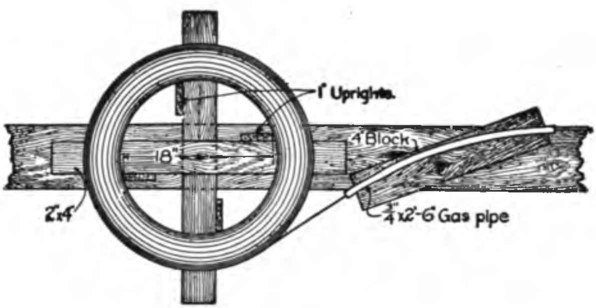


Fig. 30. Reel and device for straightening wire reinforcement.

will overcome the necessity of cutting the blocks. Steel should be placed upon the outer half of courses in order that there shall be enough mortar inside to bear against the wire and hold the blocks. Loose blocks may be placed temporarily upon the wall to hold the steel. The steel upon the courses below and above the doorways should be long enough to lap and be hooked as shown in Fig. 31.

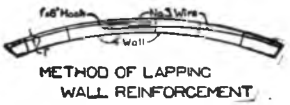


Fig. 31. Method of lapping reinforcement.

The horizontal or bed joints should be thoroly bedded to cover the steel reinforcement. The vertical joints at the block ends should be made with extreme care in order to insure perfect air and water tight joints. The difficulties that have been experienced with this silo have been mostly due to leaky mortar joints. In order to secure an air tight mortar joint, the ends of both blocks should be mortared before pressing together. A well mortared block end is shown in Fig. 32.

The outside joints should for the sake of appearance be struck neatly with the trowel as the work progresses, and they should of course all be tight. On the inside this is scarcely sufficient, as there might still be an occasional opening left between the ends of the blocks, which would permit the air to enter. In order to close all such openings, the

Fig. 32. Proper method of making vertical joint in wall.

mortar may be left hanging on the inside or cut roughly, then while still green pointed up. Some builders wash the mortar joints with a cement wash before the scaffold is raised or the work left for the night. This wash naturally brings to view any crevices which may exist. These then may be filled with mortar, and this thoroly seals the inside of the wall. This wash is composed of cement and water mixed to about the consistency of thick cream and may be applied with a broom. The wash should be applied vigorously in order to smooth down and fill the irregularities.

If the wall is rough on the inside or if silage spoils due to leaky mortar joints the wall may be plastered with good portland cement plaster.

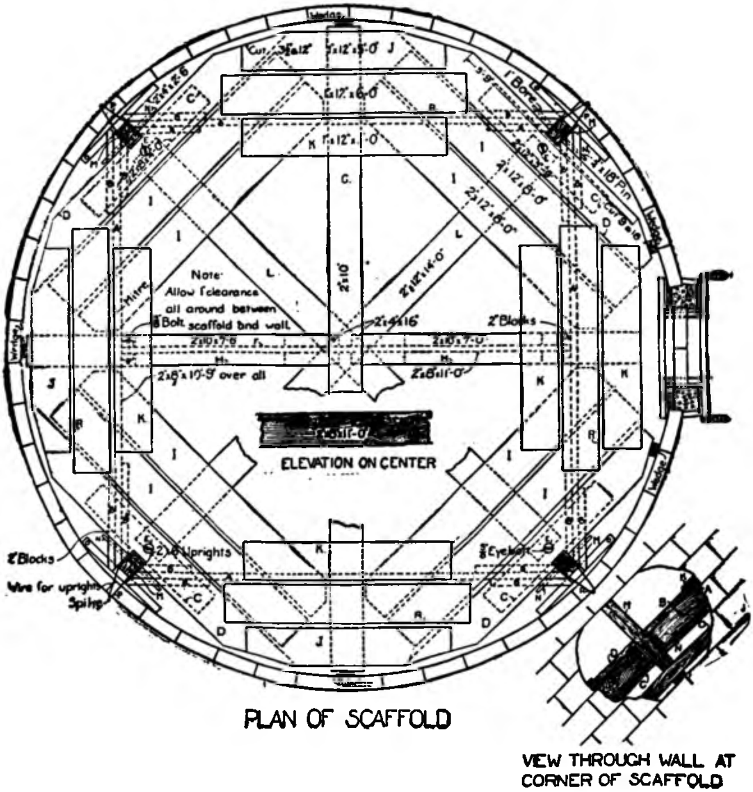


Fig. 33.

Scaffolding. It is difficult to over-estimate the advantage of a convenient, safe, and simple scaffold for any masonry construction. Three distinct types of scaffolds were tried and the one shown in the bulletin was found to be superior to any other type tried while the Agricultural Engineering Section was experimenting with the construction of this type of silo.

This scaffold is shown and parts lettered for sake of a clear description in Figs. 33 and 35. The drawing shows the top side of the scaffold, while the photograph was taken from the floor beneath. This scaffold differs from most building scaffolds in that the platform is movable. The platform itself consists essentially of a square frame work of 2x8's of reasonably clear, stiff lumber, covered with plank.

The scaffold is supported by four posts, each made of two 2x6 pieces fastened to the wall by blocks, nails and wire. Wire stretchers attached to these posts by clevises as shown in Fig. 34 may be used to lift the platform.

The common double pulley block wire stretcher has been used quite successfully. It has several advantages over other kinds. With the ordinary length of rope, the platform may be lifted 18 inches each time thus accomplishing a three foot lift by only two changes or with longer rope, the three foot lift can be accomplished at one pull. An advantage in the hoisting may be obtained by standing upon the wall instead of upon the scaffold, thus reducing very materially the weight to be lifted. A short plank lying upon the wall behind the post is convenient to stand upon. Anyone preparing to build several silos could well afford to invest in hoisting apparatus consisting of triple blocks and half-inch ropes. In any kind of hoisting apparatus, light castings, crimped chains, and unwelded eyes should be carefully avoided.

Guide. In laying any straight masonry wall, a line may be used as a guide for securing a proper shaped wall. In the case of a circular wall this is manifestly impossible. Here the need of a guide is even greater than with a straight wall as the eye of the mechanic cannot be trusted to determine a curve as he would a straight line. In the silo it is

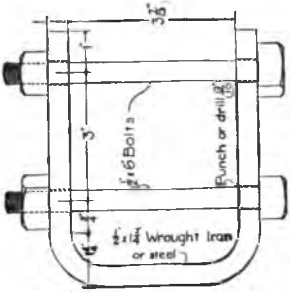


Fig. 34. Clevis for attaching scaffold and hoisting device to posts.

especially important for the sake of appearance, preservation of the silage, and strength of the wall, that it shall be circular and plumb. It is highly desirable that the guide shall be simple, easily used, and in the way as little as possible when not in use.

The device is shown in drawing Fig. 36. A piece of 3/4 or 1 inch straight gas pipe, indicated by "A," 7 or 8 feet long may be secured as a center about which to revolve a light arm "B." The outer extremity of this arm, "C," is hinged in order that it may not interfere with walking around the scaffold. Also when not in use "C" may be placed in the position shown in the figure. It is not necessary to use the guide for each block, but is very convenient for determining whether or not the blocks are properly placed, and after laying six or more blocks their position may be checked by means of this guide before the mortar joints are pointed.

Derrick. Two general methods have been followed in hoisting material on to the scaffold. In building the first Iowa silo, a 2x6 was projected out over the wall, supported from the scaffold by other light timbers, 6 feet high. A pulley was secured to the outer end of the 2x6 projecting over the wall and the material was hoisted by a horse in this manner. This method was found to interfere with the use of the guide of Fig. 56 and a derrick after the plan of Fig. 37 was used

Fig. 35. View of scaffold from center of silo floor.

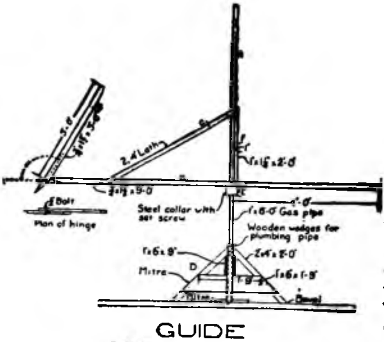


Fig. 36. Guide for laying wall plumb and to a true circle.

Forms for Door Frames. A detailed drawing of these forms, two of which are required, is shown in Fig. 38. The upper left hand view shows the elevation. The upper right hand view shows the form as seen from the side while the lower or plan view represents the form as soon from above.

The length of these forms and the location of the notch cannot be determined accurately until the wall is built up to the top of the first form. The top of the form should be sawed so that it will be flush with the top of the crosstie when the center of the crosstie is level with wall mortar joint. The notch will then be of a depth equal to the width of the block and wide enough to permit the crosstie block to rest loosely between the outer and inner form. The necessity of this will be readily seen in Fig. 39. The inside corners formed by "B," "C," and "E" should be filled with three-cornered strips which make the concrete door frame chamfered on front, leaving smoother work. The strips "I" form beveled shoulders for doors. A square shoulder should extend from jamb to jamb at lower edge of bottom door to support this door and insure a tight joint.

In the 2x6's lettered "F," holes should be bored and ½ inch bolts used. Holes should also be bored in the ends of members "A". These holes should always be bored somewhat larger than the bolt because the forms cannot be held exactly in place and the 2x6 may warp somewhat. Holes should also be bored in "A" for the long bolt extending thru the inner portion of the form. This completes the outer portion of the form.

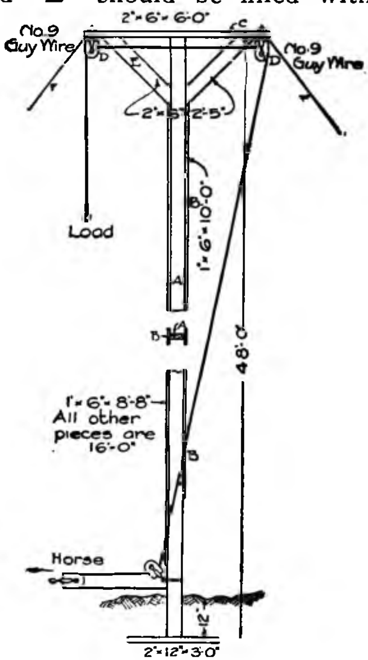


Fig. 37. Derrick.

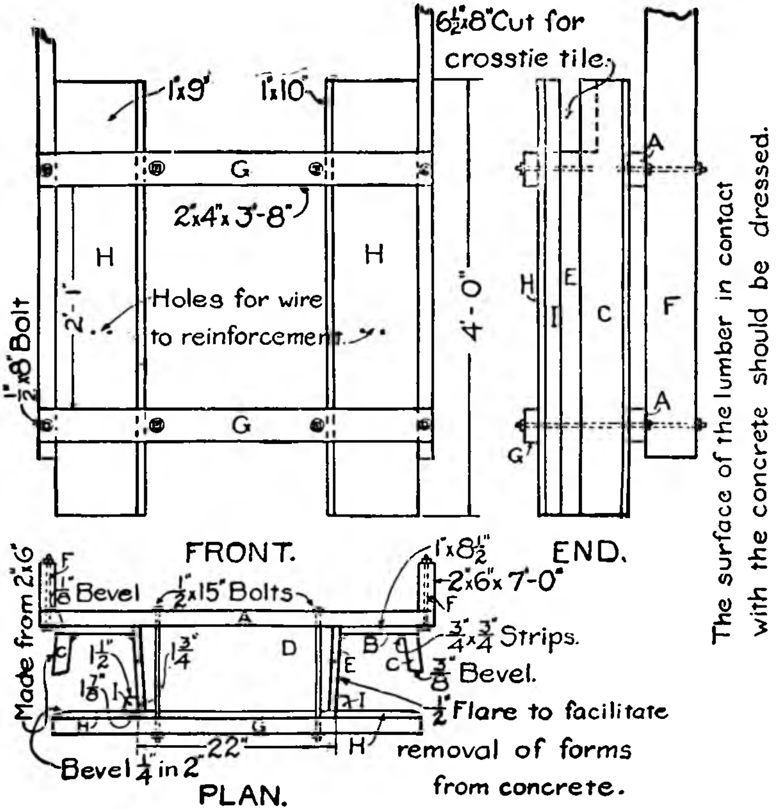


Fig. 38. Forms for continuous concrete door frame.

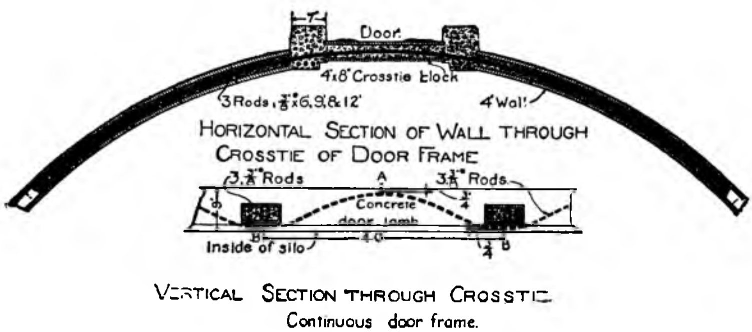


Fig. 39. Section of wall and crosstie.

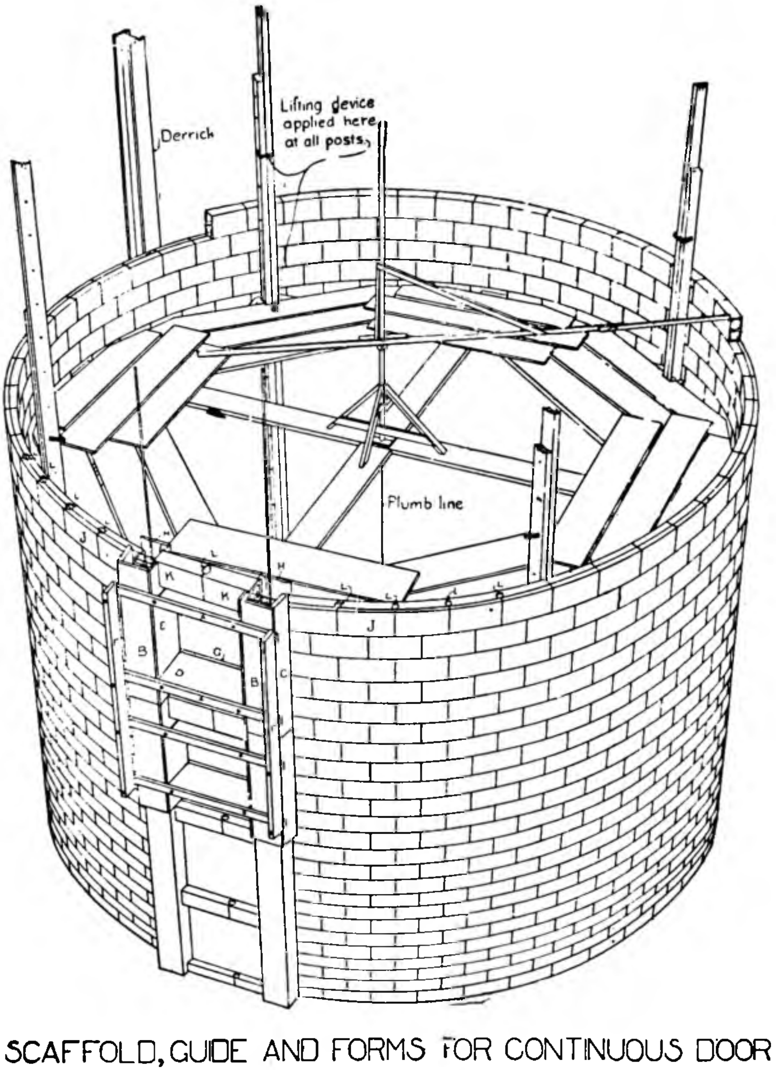


Fig. 40. Scaffold guide and forms for continuous doorway.

Reinforcement of Door Frames. If the door frame is made of the dimensions shown in Fig. 38, the amount of steel in each door jamb need not have a cross sectional area of more than ¼ square inch, that is, one ½ inch square reinforcing bar will be sufficient. In some cases, it has been convenient to use three ⅜ inch round rods as seen in

Fig. 41. Looking down upon forms of continuous door frame and steel in place ready to fill with concrete.

Fig. 41. This is slightly in excess of the quantity just mentioned but it will be found sufficient to use any kind of steel equivalent in quantity to one ½ inch by ½ inch bar, providing it is bent as shown in Fig. 39. This should be bent inside of the steel crossties, as seen at "B," and out near the outer surface of the beam at a point "A" midway between the crossties. These rods are easily secured to place by a light wire extended thru small holes in form. The reason for thus bending the steel is as follows:

If no steel were used, the pressure of the silage against the door and wall adjacent to the door would probably cause the door jamb to burst outward. In so doing, horizontal cracks or fissures would occur across the outer side of the jamb at "A" and inner side of the jamb at "B". The tendency toward the occurrence of such cracks is prevented by steel rods. In order that such rods may act advantageously, they must be near the surface which tends to open. From this it will be seen that the steel rods must be so shaped that they will not slip in the concrete. If the steel used is not regular reinforcing steel such as the corrugated or twisted bar, it should be hooked in the concrete at the ends.

A Bill of Materials for an Iowa Silo. The following is a bill of materials for an Iowa Silo 16 feet in diameter and 35 feet high, with concrete roof. This bill may be easily modified for other sizes. The different types of foundations, doors and other parts are included, from which choice may be made to suit condition:

Clay Block Foundation, Fig. 4.		
Blocks 4x8x12	130	
Cement	1½ sacks	
Lime	1½ sacks	
Sand	2-9 yards	
Gravel for back filling	3 yards	
Concrete Foundation, Fig. 4.		
Cement (according to quality of gravel)	25 to 30 sacks	
Gravel	4½ yards	
Floor—3-inch concrete:		
Cement (according to quality of gravel)	10 to 12 sacks	
Gravel	2 yards	
Wall:		
Blocks, 4x8x12	3000	
Freight on 18 to 24 tons.		
Cement	20 sacks	
Lime	5 barrels	
Sand	2 yds.	
Steel No. 3 wire, hard	400 lbs.	
18 pcs. 1.2"x½"x18' reinforcing bars	276 lbs.	
No. 12 soft wire	5 lbs.	
Scaffold:		
Posts, 20 pcs. 2"x6"x16'		320 bd. ft.
Frame work, 5 pcs. 2"x8"x12'		80 bd. ft.
Plank below scaffold, 2 pcs. 2"x8"x16'		44 bd. ft.
Platform, 2 pcs. 2"x12"x14'	56 bd. ft.	
2 pcs. 2"x10"x16'	54 bd. ft.	
6 pcs. 2"x12"x16'	192 bd. ft.	
4 pcs. 1"x12"x16'	64 bd. ft.	366 bd. ft.
Braces for holding post before wall is started:		
8 pcs. 1"x6"x16'		64 bd. ft.
4 wire stretchers.		
4 clevises.		
Continuous Door Forms:		
Lumber, 1 pc. 2"x4"x8'		
2 pcs. 2"4"x14'	24 bd. ft.	
2 pcs. 2"x6"x16'	32 bd. ft.	56 bd. ft.
4 pcs. 1"x10"x14'	47 bd. ft.	
1 pc. 1"10"x8'	7 bd. ft.	54 bd. ft.
Eight ½"x7" machine bolts.		
Eight ½"x15" machine bolts.		
Guide:		
¾"x½"x14' stop.		
2 pcs. 4' lath.		
2"x4"x8'		5 1-3 ft.
8' gas pipe ¾" or 1".		

Derrick:	
3 pcs. 2"x6"x16'	48 bd. ft.
1 pc. 2"x6"x6'	6 bd. ft.
6 pcs. 1"x6"x16'	48 bd. ft.
3 guy wires (100 ft. each) No. 9 wire	
Continuous Doors:	
Fence flooring	152 bd. ft.
Tar paper or prepared roofing	10 sq. yrds.
6 d. nails.	
Roof:	
Cornice blocks	175
Cement (according to quality of gravel)	16 to 20 sacks.
Gravel	2½ yds.
Steel 3 pcs. ½"x½"x18'	46 lbs.
Woven wire fencing 24 inches wide	225 ft.
False Work:	
26 pcs. 1"x12"x10' sheeting	260 bd. ft.
8 pcs. 2"x6"x10' rafters	80 bd. ft.
1 pc. 4"x4"x 6' or 1 cedar post	8 bd. ft.
5 pcs. 1"x8"x16'.	
4 pcs. 1"x6"x16'	86 bd. ft.
8 forgings shown in Fig. 8.	

Labor Required for Construction of Iowa Silo. The following estimate is based upon the use of 4x8x12 curved

Fig. 42. View of doorway, looking toward the roof. Notice the size of the openings.

blocks, and a silo 16 feet in diameter and 35 feet high with concrete roof. By modifying this estimate to suit any other size of silo or local labor conditions, a quite definite idea of labor cost may be obtained.

Excavation—
- 4 men 5 hrs.
- 1 team 5 hrs.

Footing—
- Clay Block, Figure 4.
  - Mason 3 hrs.
  - Mason helper 3 hrs.
  - Unskilled labor 3 hrs.
- Concrete, Figure 4.
  - Mason 6 hrs.
  - Mason helper 6 hrs.
  - Unskilled labor 6 hrs.

Floor—
- Mason 5 hrs.
- Mason helper 5 hrs.
- Two unskilled laborers 5 hrs. each.

Continuous Door Forms—
- Carpenter 15 hrs.

Scaffold—
- Carpenter 10 hrs.
- Unskilled laborer 10 hrs.

Wall—
- Mason 60 hrs.
- Mason helper 60 hrs.
- Two unskilled laborers 60 hrs. each.

Doors—
- Continuous Type:
  - Carpenter 5 hrs.

Roof:
- Cornice Block setting:
  - Mason 6 hrs.
  - Mason helper 6 hrs.
  - 2 unskilled laborers, 6 hrs. each.

Framing false work:
- Carpenter 6 hrs.

Placing false work:
- Mason 3 hrs.
- Mason helper 3 hrs.
- Two unskilled laborers, 4 hrs. each.

Placing concrete:
- Mason 8 hrs.
- Mason helper 8 hrs.
- Two unskilled laborers, 8 hrs. each.

Removal of false work and scaffold:
- Three unskilled laborers, 6 hrs. each.

THE PIT SILO.

In some parts of Iowa where the soil is a loess formation to a depth of 25 feet or more, pit silos have been used successfully.

One method of construction is to first dig a circular trench about 10 inches wide, 3½ feet deep and the diameter of the silo. This trench is filled with concrete and prevents damage to the top part of the wall by washing or freezing. The pit is then excavated, the walls being cement plastered as excavation proceeds below the concrete.

A more permanent construction is to brick up the walls from bottom to top. The cement plaster usually gives some trouble by coming loose from the dirt wall.

The pit silo cannot be used in a soil where there is any seepage, or where the soil is of such a nature that it is likely to cave in.

To hoist the silage out of the pit silo during the feeding season, a box of suitable size may be filled, and lifted with equipment the same as used for hoisting hay into a barn.

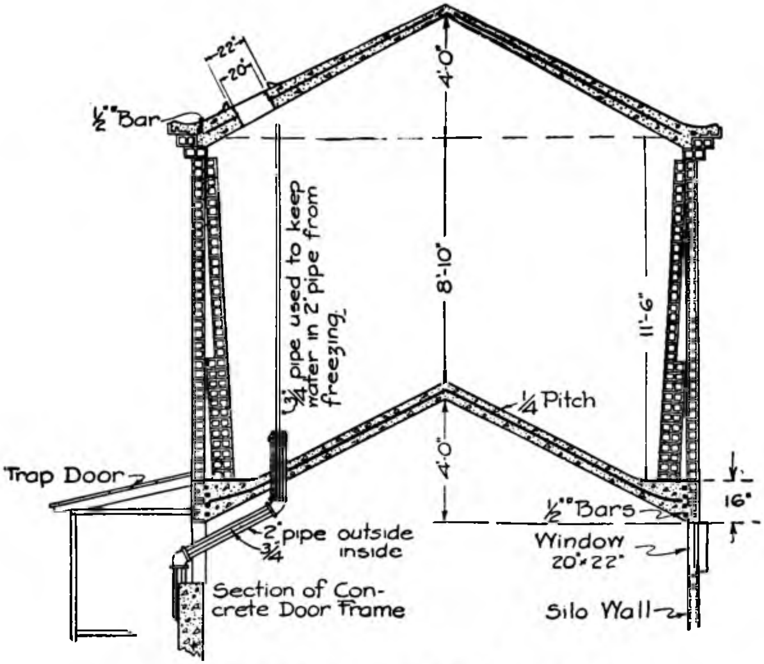


Fig. 43. Drawing of Iowa Silo and Water Tank.

MASONRY SILO AS WATER TOWER.

The masonry silo makes without additional cost a good tower to support a water supply tank where a water supply system is desired. The Agricultural Engineering Section has been experimenting for several years in the construction of elevated tanks of masonry. Some difficulty has been experienced in making the wall water tight in a tank such as shown in Fig. 43. The inner surface of a tank wall of this type was treated with a coating of asphalt and then cement plastered in 1915. This tank is giving no trouble from leakage at the present time, and we believe that this treatment will make this type of tank successful. The water supply pipe to the tank must be well insulated.